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Anoop Kumar Singh

High Resolution Palaeoclimatic Changes in Selected Sectors of the Indian Himalaya by Using Speleothems

Past Climatic Changes Using Cave Structures

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Doctoral Thesis accepted by
the Kumaun University, Uttarakhand, India

Springer

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ISSN 2190-5053 ISSN 2190-5061 (electronic)
Springer Theses
ISBN 978-3-319-73596-2 ISBN 978-3-319-73597-9 (eBook)
https://doi.org/10.1007/978-3-319-73597-9

Library of Congress Control Number: 2017962981

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The registered company is Springer International Publishing AG
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Supervisor's Foreword

The Himalaya not only influences the rainfall pattern in India but also obstructs the path of the cold winds coming from the north because of altitude and location. The Inner Asian high-pressure systems and winter Westerlies are main components of the Himalayan climate, and a combined impact of rainfall, latitude, and altitude mainly affects the climate pattern. The region mainly experiences two seasons, i.e., summer (June to September) and winter (October to May). The Indian Summer Monsoon (ISM) decreases toward northwest India where Western Disturbances (WDs) play a major role in the annual precipitation. Therefore, the role of the WDs cannot be overlooked while using any archive or proxy for the past climatic changes in the Indian Himalaya. Taking this into account as well as knowing that the high-resolution palaeoclimatic records are scarce from the Indian Himalaya, Anoop Kumar Singh was given an assignment on high-resolution past climatic changes in selected sectors of the Indian Himalaya employing cave speleothems, particularly for the last ~15 ka period and undoubtedly the results should be very helpful to develop the models for ISM variability and WDs through an improved understanding of the monsoon–climate interaction.

The doctoral thesis encompasses study of six cave stalagmites, chronology of which was constructed on the basis of 35 U/Th and 5 AMS dates. Other proxies used were SEM analysis, XRD, and Mg/Ca ratio in order to differentiate calcite from aragonite, in addition to about 1500 samples for $\delta^{18}O$ and $\delta^{13}C$ isotopes for reconstructing past precipitation model. Three major events were identified, e.g., Older Dryas (OD), Bølling–Allerød (BA) period, and Younger Dryas (YD) at ca. 14.3–13.9, 13.9–12.7, and 12.7–12.2 ka BP, respectively. While comparing NW Himalayan record with Central Himalaya, there appears a similar trend in general but a shift in the duration of YD event, proving that the past climate of these two sectors also does not co-vary. The study also showed a gradual reduction in the precipitation from 4.0 ka BP onward for about a millennium with a peak arid period between 3.2 and 3.1 ka BP—a period correlated with fall of the Harappan–Indus civilization which finally collapsed due to severe scarcity of water reserves at 3.1 ka BP.

Considering very high variability in the $\delta^{18}O$ and $\delta^{13}C$ values, Anoop believes that the precipitation in the Himalayan foothills was a result of two sources of moisture and therefore he suggests that the WDs contributed significantly in the total rainfall during the Holocene period in the Indian Himalaya. This must be a reason for anti-correlation in the climatic pattern from Mid-Holocene onward between Himalaya and Peninsular India, the former received substantial precipitation from WDs.

Interestingly, the LIA in the Indian Himalaya was wetter compared to that in the post-LIA period. This is because during ISM break conditions, the moisture winds moved directly from the south to the Himalayan foothills and the WDs extended to the southern edge of the Tibet Plateau. As a result, during this period, the Himalayan southern slopes received high precipitation than the core monsoon zone.

I was deeply impressed by Anoop's excellent and matchless depth of understanding of the Holocene climatic process. During the doctoral programme, he visited several well-known laboratories in India and abroad as well as attended several training programmes to get skilled in this subject, refine his research, and get exposed to variety of climate archives and proxies.

Nainital, India
August 2017

Prof. B. S. Kotlia

Parts of this thesis have been published in the following journal articles:

1. Kotlia BS, Singh AK, Zhao J, Duan W, Tan M, Sharma AK, Raza W (2017) Stalagmite based high resolution precipitation variability for past four centuries in the Indian Central Himalaya: Chulerasim cave re-visited and data re-interpretation. Quaternary International 444 (A): 35–43
2. Kotlia BS, Singh AK, Sanwal J, Raza W, Ahmad SM, Joshi LM, Sirohi M, Sharma AK, Sagar N (2016) stalagmite inferred high resolution climatic changes through Pleistocene-Holocene transition in Northwest Indian Himalaya. Journal of Earth Science and Climate Change 7:3 http://dx.doi.org/10.4172/2157-7617.1000338
3. Kotlia BS, Singh AK, Joshi LM, Dhaila BS (2015) Precipitation variability in the Indian Central Himalaya during last ca. 4,000 years inferred from a speleothem record: Impact of Indian Summer Monsoon (ISM) and Westerlies. Quaternary International 371: 244–253
4. Joshi LM, Kotlia BS, Ahmad SM, Wu C-C, Sanwal J, Raza W, Singh AK, Shen C-C, Long T, Sharma AK (2017) Reconstruction of Indian monsoon precipitation variability between 4.0 and 1.6 ka BP using speleothem δ^{18}O records from the Central Lesser Himalaya, India. Arabian Journal of Geosciences http://dx.doi.org/10.1007/s12517-017-3141-7

Acknowledgements

For me, doing the research work was a real lifelong experience. This thesis is a crop of helping hands and support of a number of individuals. Foremost, I am extremely grateful to Prof. B. S. Kotlia for supervising the thesis and for being the driving force behind the present study. His cosmic supervision, motivation, support, and appreciation in every way was unforgettable.

I would like to convey my sincere thanks to Prof. A. K. Sharma, Head, Department of Geology, Kumaun University, Nainital for providing me the departmental facilities. I sincerely thank Prof. Santosh Kumar, Dean, Faculty of Science for his fruitful suggestions. I am pleased in recording my sincere gratitude to Director, CSIR-National Geophysical Research Institute, Hyderabad for providing the laboratory and other necessary facilities during the analytical procedures. My heartiest thanks to Prof. Augusto Mangini, University of Heidelberg (Germany) for providing most of the U/Th dates.

I gratefully acknowledge Dr. Lalit M. Joshi for his multiple help, emotional support, and constant backup that cannot be expressed in words. I am highly indebted to Mr. Bachi S. Dhaila for his kind support and encouragement during my research period. It is my great pleasure to express my sincere gratitude to Dr. Syed Masood Ahmad, Mr. Netramani Sagar, Mr. Waseem Raza, Mr. Tabish Raza from NGRI, Hyderabad, and Dr. Mahjoor Lone (presently at National Taiwan University Taipei, Taiwan) for their generous help during sample analysis. In addition, I express my sincere thanks to G. Suseela, Sadia Farnaaz, Shiva, Shivasis, and Santosh from NGRI, Hyderabad for helping me during the isotopic analysis. I am beholden to Prof. D. C. Pande (Registrar and Chief Warden Kumaun University, Nainital) for moral support and help in various ways in completing the thesis. I am also obliged to the ISRO, Ahmedabad for financial assistance. Additionally, I am also grateful to the MoES (MoES/P.O./Geosci/43/2015), New Delhi for the financial help during later half of my research period.

Nainital, India
August 2017

Anoop Kumar Singh

Contents

Abbreviations

$\delta^{18}O$	Stable oxygen isotope ratio ($^{18}O/^{16}O$) in a sample relative to that in a standard
$\delta^{13}C$	Stable carbon isotope ratio ($^{13}C/^{12}C$) in a sample relative to that in a standard
AMS	Accelerator Mass Spectrometry Radiocarbon Dating
ASM	Asian Monsoon System
BA	Bølling–Allerød
EASM	East Asian Summer Monsoon
EDS	Energy Dispersive X-ray Analysis
ENSO	El Niño–Southern Oscillations
GNIP	Global Network of Isotopes in Precipitation
IOD	Indian Ocean Dipole
ISM	Indian Summer Monsoon
ITCZ	Inter-Tropical Convergence Zone
LIA	Little Ice Age
LLJ	Low-Level Jet streams
Mg/Ca	Magnesium/Calcium ratio
NAO	North Atlantic Oscillation
OD	Older Dryas
SEM	Scanning Electron Microscope
U/Th	Uranium–Thorium dating
XRD	X-ray Diffraction
WDs	Westerlies or Western Disturbances
YD	Younger Dryas

Chapter 1
Introduction

Monsoon is one of the complex rain bearing features of Earth's climate. The Asian Monsoon System (ASM) is a large and most extensive monsoon pattern in the world as well as important component of global climate system (Morrill et al. 2006). It strongly affects most of the nations of south and south-east Asia. The ASM has two dominant monsoon patterns, e.g., East Asian Summer Monsoon (EASM) and Indian Summer Monsoon (ISM). The EASM is a monsoonal stream that carries wet air from the Indian and Pacific Oceans to East Asia and affects parts of Japan, Koreas, Taiwan, Philippines, Hongkong, Indo-china and much of mainland China (Webster et al. 1998; Trenberth et al. 2000; Ding and Chan 2005). It is derived by temperature difference between the Pacific Ocean and the Asian continent. The ISM pattern of the Indian subcontinent, different from the rest of Asia decides the economic and agricultural growth of India and its dramatic pattern and intensity are great challenge for climatologists to reconstruct the past climatic conditions and also future predictions.

The ISM arrives from southwest direction (Arabian Sea) to land, and brings rain to most parts of the Indian subcontinent (Rao 1976; Agnihotri et al. 2002; Gadgil 2003) during the months of June–September and contributes about 80% precipitation of the total annual rainfall (Gadgil 2003) while remaining is received from winter monsoon, e.g., North East monsoon (NE monsoon) and Westerlies (WDs). The ISM splits into two branches (Fig. 1.1), (i) The Arabian Sea branch and, (ii) Bay of Bengal branch. It is divided into three different streams on arriving in the mainland of India. The first stream strikes the elevated Western Ghats (Ananthakrishnan et al. 1967; Rao 1976; Ananthakrishnan and Soman 1988; Soman and Kumar 1993; Chakraborty et al. 2006; Rao et al. 2010; Goswami 2012) at almost right angle (Fig. 1.1) and provides extremely heavy rainfall. The second stream enters Narmada-Tapi troughs and reaches Central India. It does not cause much rain near the coast but is very much responsible for precipitation in the Indo-Gangetic Plains. The third stream moves in a North-Easterly route parallel to the Aravalli Range. Since the orientation of the Aravalli Range is parallel to the direction of prevailing monsoon winds, it does not offer a major blockage in Rajasthan. The Bay of Bengal branch is main cause of

A. K. Singh, *High Resolution Palaeoclimatic Changes in Selected Sectors of the Indian Himalaya by Using Speleothems*, Springer Theses,
https://doi.org/10.1007/978-3-319-73597-9_1

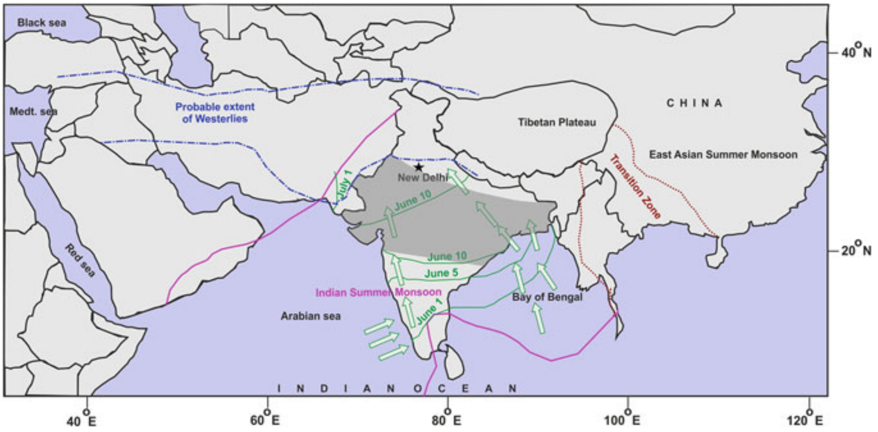

Fig. 1.1 Extent of present day ISM and WDs (after Kotlia et al. 2015)

precipitation in Northeast India and further moves towards the Indo-Gangetic Plain. It is divided into two distinct streams; first stream of Bay of Bengal branch hits the western coast of Burma where Arakan and Tenasserim mountains receive heavy rainfall (Gadgil 2003). Another southerly stream crosses the Ganga-Brahmaputra delta and reaches Meghalaya. This moves towards southern slopes of Assam hills. The rain bearing winds decrease from south to north and east to west.

The NE monsoon (October–December) brings rain to several places in south India (Prasad and Enzel 2006). The ISM withdraws from the extreme north-west end of the country in September, from the Peninsula by October and from the extreme south-eastern tip by December. The NE Monsoon contributes mainly to coastal Andhra Pradesh and Tamil Nadu-Pondicherry.

Westerlies or Western Disturbances (WDs) bring heavy rainfall/snow fall in low lying areas in western Himalayan region, particularly over Northwest India. The WDs are active in the winter months (November–February) and are important for Rabi crops (wheat). The WDs (between 30° and 60° latitude) originate mostly from the Mediterranean Sea and move eastward towards India across Afghanistan/Pakistan (Benn and Owen 1998; Kotlia et al. 2015). They split into two branches in Asia due to orographic barrier of the Himalaya and the Tibetan Plateau (Pang et al. 2014).

1.1 Indian Summer Monsoon (ISM) Variability

It is shown that the ISM rainfall over India occurs in intermittent spells of active and break cycles (Ramamurthy 1969; Sikka and Gadgil 1980; Krishnamurthy and Kinter 2003).

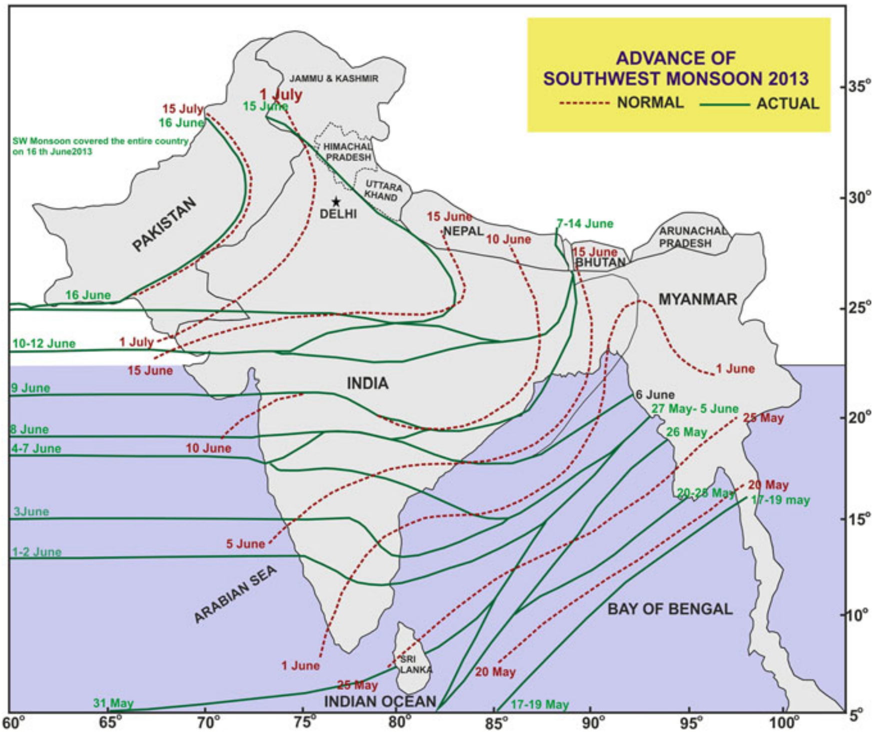

Fig. 1.2 Advance of the ISM within 15 days in the year 2013

The break spells or intervals of droughts (Sikka 1980) are described as interruption of several days in the peak ISM months. The active spells are defined as development of the ISM disturbances (wet and flood periods) in a short period (Murakami 1976). The ISM intensity depends on many parameters, e.g., coupled heating-cooling between land and sea, Inter-Tropical Convergence Zone (ITCZ), El Niño-Southern Oscillations (ENSO), North Atlantic Oscillations (NAO) etc. For example, the ISM covered the entire country before 15 days from regular schedule in the year 2013 (Fig. 1.2), during which several parts of North India (Uttarakhand) and NE India witnessed floods. It was an El Niňo year (Weaker monsoon year) but the amount of precipitation in June was totally different. Thus, it is very much difficult to predict the behaviour and intensity of monsoon. Some other examples are floods in Mumbai (2005), Uttarakhand (2013), Kashmir (2014) (Singh et al. 2014) and the droughts in NE India, Bihar and Jharkhand in 2013 (Indian Meteorological Department report 2013).